THE IMPORTANCE OF LOW INTENSITY RAINFALL ON LANDSLIDE OCCURRENCE

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ABSTRACT

A simulation modelling to assess the influence of low intensity rainfall on landslide event was performed. The input data were provided from references of previous studies, field survey and laboratory tests. Two different rainfall patterns were applied. Those were the single event of rainstorm, i.e. one hour of 75 mm/day rainstorm and the long-sustained antecedent rainfall with low intensity, i.e. 13 hours of 1.9 mm/day rain. This simulation shows that low intensity of long sustained antecedent rainfall can result in slope stability reduction and landslides, when the hydraulic conductivity of the slope is low (about 2.51×10^{-6} m/sec) and initial position of groundwater table is shallow (about 1 m to 3 m depth).

INTRODUCTION

Rain-induced landslides on gentle slopes frequently occur in Java and have become the major problems in highway network (Heath, et al 1988; Heath and Sarosa, 1988). Some previous studies suggested that the landslide occurrences were induced by high intensity of rainfall (rainstorm) (Brand, 1984;Gostelow, 1991; Keene, 1992). However in this study, the importance of long-sustained rainfall with low intensity was assessed by applying a simulation modeling.

Shear strength in the slopes can change in response to the rainfall. If this change results in the condition in which the shear strength of the slope is exceeded by the shear stress to cause the slope movement, landslide occurs. This change mainly due to groundwater table fluctuations in the slope which are induced by rainfall. Therefore, in this study computer simulations were performed to predict the groundwater table fluctuations related to soil shear strength changes in the slopes. Slope hydrological response to the high intensity rainfall and prolonged low intensity rainfall thus could be investigated.

The simulation was carried out using the unsaturated and saturated flow modelling package SEFSLOPE. The validity of the governing equations and assumptions used in simulating the flow, boundary conditions and slope geometry, had been discussed by Karnawati (1996).

SLOPE CONDITIONS AND RAIN PATTERNS

Simplified slope geometry and soil engineering properties were used. The soil forming the slope was assumed to be homogeneous. As the period of simulation was hours or days (less than a week), slope geometry and engineering properties were also assumed to be constant.

In subsequent simulations slope hydrological conditions were modelled in more detail. The hydraulic head variations in response to rainfall were investigated. Several rainfall patterns were applied to investigate the sensitivity of hydrological conditions and stability to rainfall pattern (i.e. to compare short, intense storms with more sustained rainfall events).

1. Model slope geometry

A single slope unit representing a natural slope in Java was simulated. All simulations were carried out on a model slope with 15° inclination and 20 m height (Figure 1). This geometry was considered to be representative of typical gentle slopes which commonly cause major problems on highways.

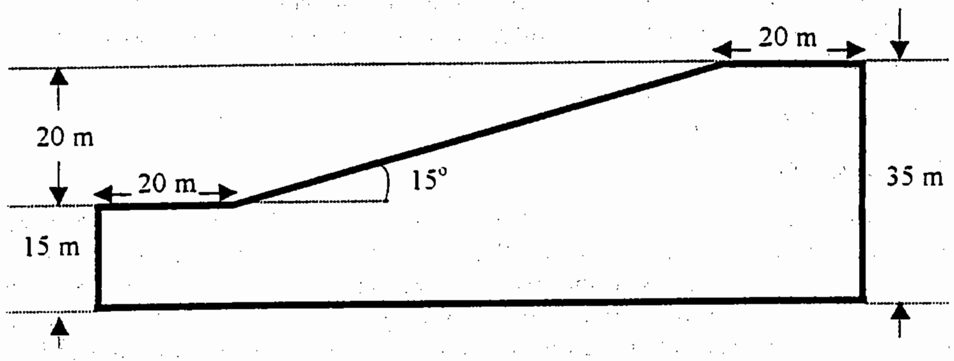


Figure 1. Model slope geometry

According to Heath et al (1988), saturation front can migrate up slope from the toe during storm events in Java. The mechanism is described in detail by Whipkey and Kirkby (1978). The boundary conditions in the model (in particular the thickness at the toe) were selected in order to simulate this mechanism. The impermeable base of the model was horizontal (rather than parallel to the ground surface) in order to allow simulation of deep seated circular failure (Figure 2).

2. Model soil properties

Sets of soil engineering properties which were representative of halloysitic clay were selected (Table 1.). This is the soil type that commonly found in the landslide sites in Java. (Heath, 1984; Sugalang, 1989; Karnawati, 1996). Properties of the soil (except for the soil volumetric water content) were selected values taken from the previous studies. The relationship between volumetric water content (θ) and suction (ψ) was

normally shown as a soil-moisture retention curve. In this study the relationship for halloysitic soils were established by laboratory testing on samples collected from Margayasa at Purworejo Central Java, and representative values had been taken for modelling work.

Table 1. Model soil properties

Soil properties	Magnitude
Shear strength parameters:	
a. Cohesion	8 kPa
b. Frictional angle	17.4^{o}
Specific gravity	2.68
Void ratio	1.4
Unsaturated bulk unit weight	15.6 kN/m^3
Saturated bulk unit weight	17.0 kN/m^3
Saturated permeability	2.51×10^{-6} m/s
Saturated volumetric water content (porosity)	0.72 cm^3/cm^3

3. Model slope hydrology

Initial slope hydrological condition representing the condition in wet season in Java were using in modelling (Figure 2). The groundwater table was shallow. It was 1 m below the foot slope and 3 m below the top slope. Outflow was permitted through the left hand side boundary (this was a constant head boundary), but no inflow was permitted across the right hand side boundary.

The surface boundary was specified as constant flux to represent infiltration or evaporation. The bottom boundary was a no flow boundary. This is representative for slopes underlain by relatively impermeable bedrock, which is the usual condition in Java. Therefore, all of those boundaries specified are representative for a single gentle hillslope in Java.

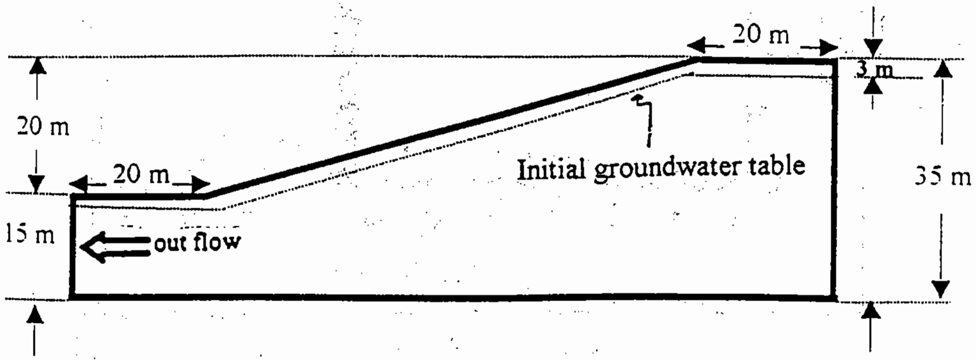
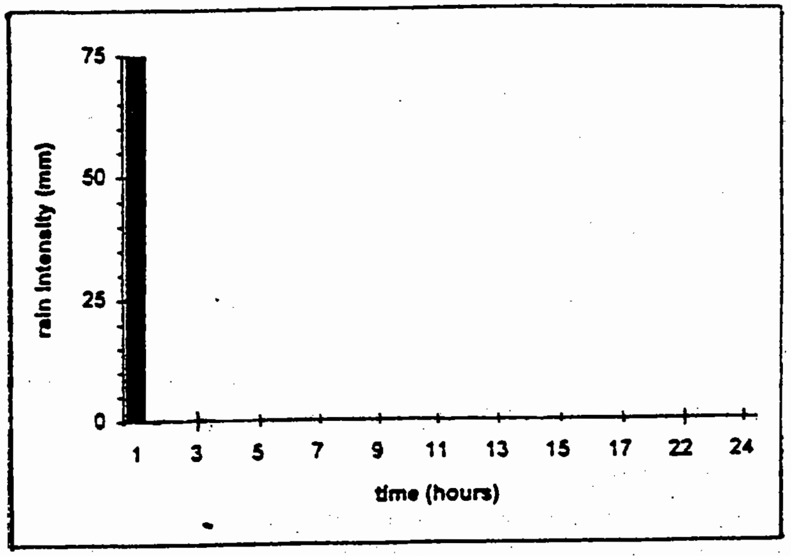


Figure 2. Boundary conditions and initial groundwater table position in wet season

4. Simulated rainfall patterns

This study was aimed at identifying rainfall patterns that were critical for slope stability. The rainfall patterns (Figure 3) applied in simulations are as follows:

a)



b)

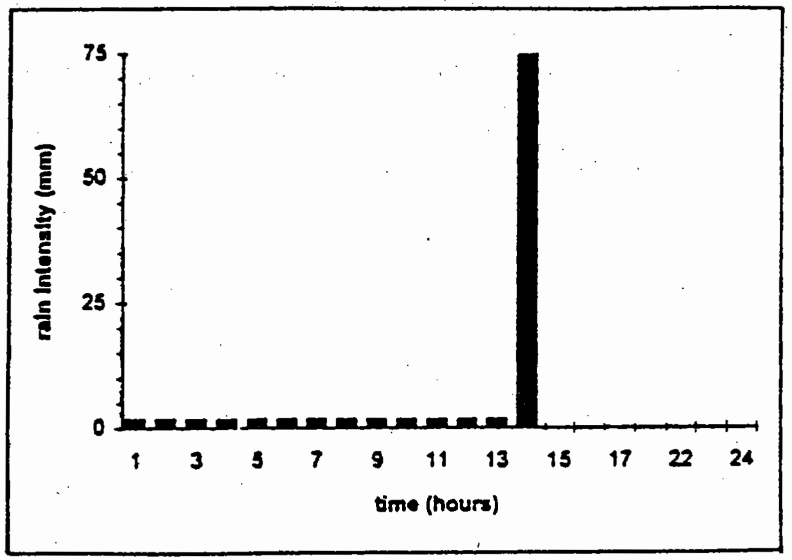


Figure 3. Daily rainfall patterns: a) **75** mm/hour rainstorm followed by 23 hours no rainfall and b)

1. 1 hour of 75 mm rainstorm followed by 23 hours no rainfall (simulation A)
2. 13 hours of 1.9 mm/hour antecedent rainfall*, followed by 1 hour of 75 mm/hour rainstorm and then 10 hours no rainfall (simulation B).

The rainstorm flux was defined based on rainfall data collected in Puncak Area, West Java, and this considered as the most severe rainstorm in Java. Meanwhile, the low intensity of antecedent rainfall was defined by statistical assessment on rainfall data collected from Puncak Area in West Java and Tol Road Area in Semarang Central Java.

Both patterns allowed the role of single event of high intensity rainfall as well as antecedent rainfall in inducing failure to be assessed. Sensitivity to rainfall intensity and duration were also investigated by comparing simulations of both patterns.

SIMULATION DESIGN

The simulations were designed as listed in Table 2. The objectives of such simulations were to assess severity of single rainstorm event (i.e. 75 mm/day rainfall) and the significance of the long-sustained antecedent rainfall (i.e. 13 hours of 1.9 mm/hour rainfall).

Table 2. Simulation design

Simulations	Hour	Average rain or evaporation	Remarks
A	0-1	Rain of 4.7×10^{-6} m/sec (75 mm/hour)	1 hour rainstorm followed by 23 hours evaporation
	2-24	Evaporation (0.125 mm/hour)	
B	0-13	Rain of 1×10^{-7}mm/sec (16 mm/day)	1.9 mm/hour rainfall for 13 hours followed by 1 hour rainstorm, then 10 hours of evaporation (0.125 mm/hour)
	13-14	Rain of 4.7×10^{-6} mm/sec (75 mm/hour)	
	14-24	Evaporation of 0.125 mm/hour	
C	0-24	0 mm/day (no rain), but evaporation of 0.125 mm/hour	24 hours evaporation of 0.125 mm/hour

SIMULATION RESULTS

Graphs in Figure 4 illustrate the factor of safety variations. These variations show that shear strength of the slope also varied through the time in response to the applied rainfall. Since, the factor of safety is the ratio between shear strength available in the slope to the moving force to cause the slope failure (landslide).

Unique patterns of factor of safety changes were recorded in the graphs. In the simulation A (graph A) factor of safety gradually decreased and reached the minimum value, but then gradually rose to reach the initial value. Thus shear strength in the slope also gradually decreased to reach the minimum value, and then gradually rose to reach the initial value.

This graph A also shows that the landslide event occurred when the strength was minimum, i.e. three hours after the 75 mm rainstorm ceased. Hence the event was delayed for three hours. Mechanism of the delay can be explained as follows (see also Figure 5).

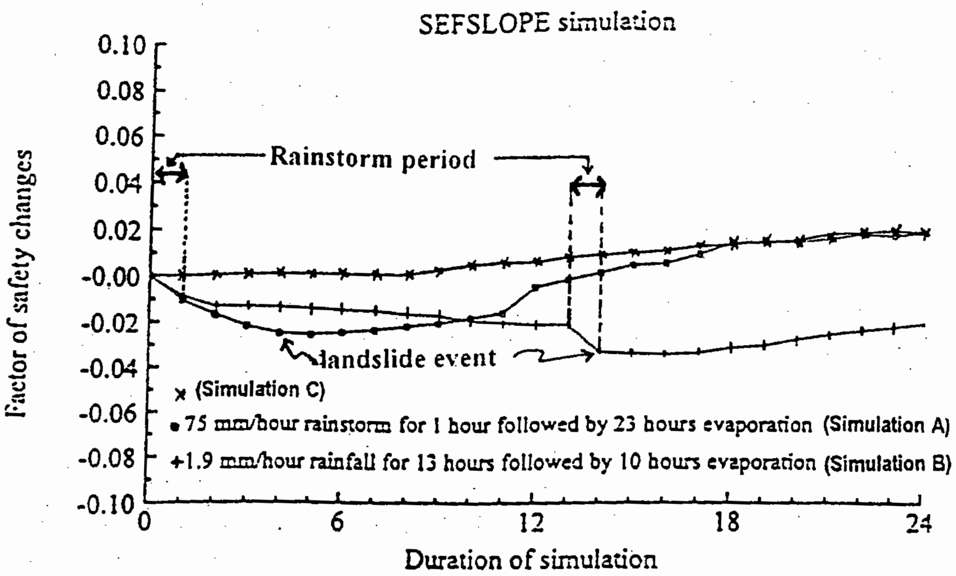
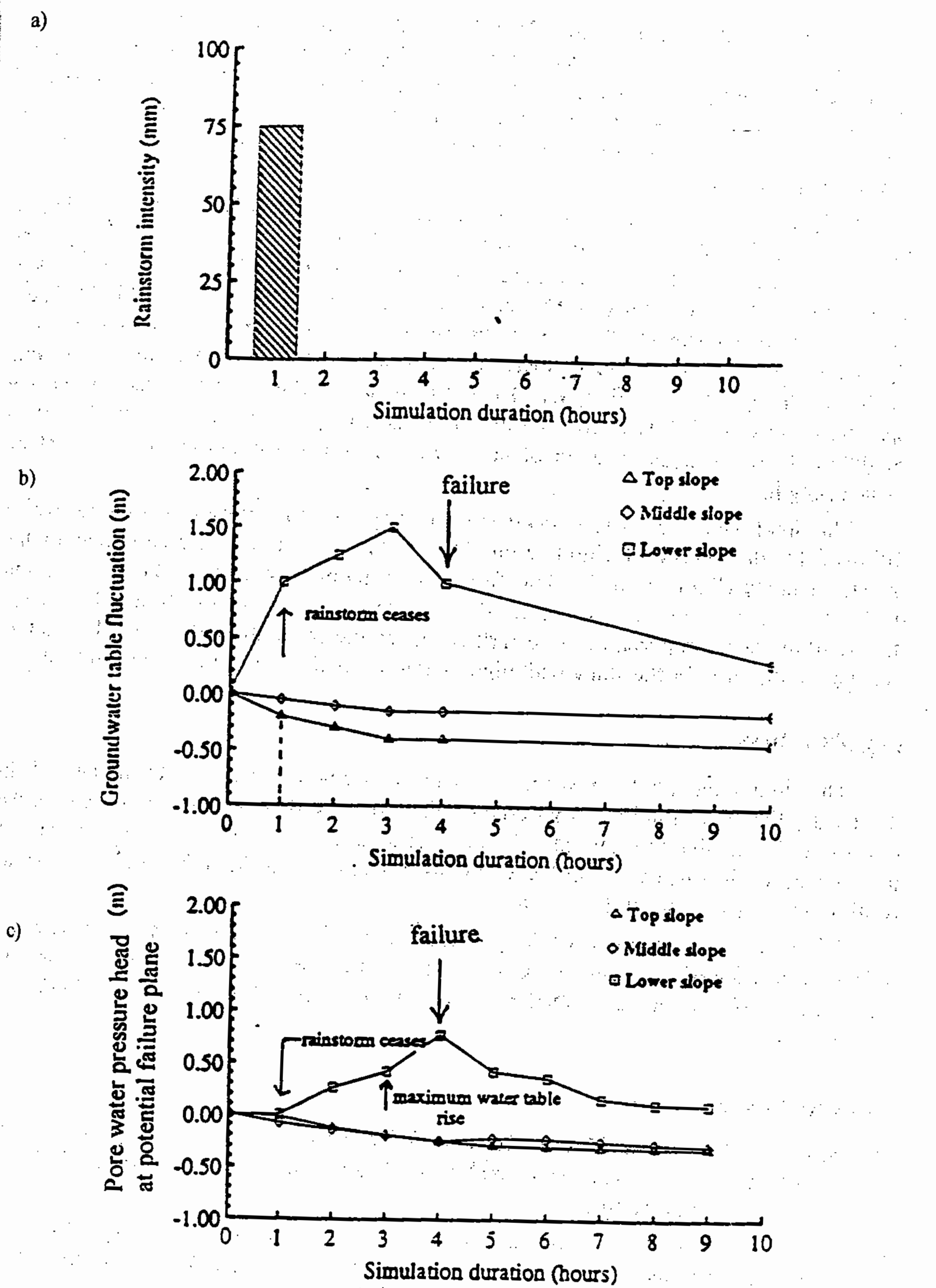


Figure 4. Factor of safety variations in response to two rainfall patterns. Initial factor of safety 0.84

Figure 5b shows that the groundwater table in lower slope gradually rose in response to the one hour of 75 mm rainstorm. This gradual rise of groundwater table continued, although the rainstorm had ceased. Two hours after the rainstorm ceased, the groundwater table reached the maximum level, but then it gradually decreased to reach the initial level. The slow rise of groundwater table was because the slope hydraulic conductivity was low, i.e. 2.51 x 10^{-6} m/sec. As a result, the infiltration of rain water (rain influx) also proceeded at slow rate. This also explained why the maximum rise of groundwater table was delayed.

The fluctuation of groundwater table accordingly brought about to the change of pore water pressure of the soil in slope (Figure 5c). However, both processes were not simultaneous. The peak of this change of pore water pressure occurred one hour after the groundwater table reached the maximum level. This delay was also due to the low hydraulic conductivity in the slope. Thus, the soil pore water pressure took some time to respond to the groundwater table fluctuation. In conform with this phenomenon, the achievement of minimum shear strength, i.e. when the pore water pressure achieved the maximum value, also was delayed for one hour after the achievement of maximum level of groundwater table. Therefore, the landslide occurred 3 hours after rainstorm ceased



It was also apparent in Figure 5b and 5c that the groundwater table and soil pore water pressure in the middle and top parts of the slope behaved in different way. Instead of fluctuating, both groundwater table and soil pore water pressure just slightly decreased in those slope parts. This probably because of lateral flows to the lower slope. The vertical boundary at the lower slope which was the only outflow boundary (Figure 2) controled this lateral flow.

Different pattern of factor of safety changes was also recorded in graph B (Figure 4), when the different rainfall pattern was applied. At the first stage the factor of safety decreased in a slow rate. Such decreased was in response to the 13 hours of low intensity antecedent rainfall. The rainfall influx recorded was about $1x10^{-7}$ m/sec (Table 2). Then, this 13-hour-antecedent rainfall was followed by the one hour of 75 mm rainstorm. Consequently, the factor of safety suddenly reduced. This reduction was quite sharp due to the much higher rain influx, i.e. 4.7×10^{-6} m/sec (Table 2) proceeded. When the rainstorm had ceased, this factor of safety then gradually increased to reach the initial condition. Those changes of factor of safety were in conform with the changes of slope shear strength.

The total factor of safety decreased in response to antecedent rainfall which followed by the rainstorm (Simulation B) was larger than the decrease due to the rainstorm alone (Simulation A). The former was about 0.04 and the later was about 0.025. Therefore, in this case where the slope has low hydraulic conductivity, the antecedent rainfall has an important role to further reduce the shear strength. Nevertheless this may be not the case for the slope with high hydraulic conductivity such as in sandy slope.

CONCLUSION

The simulation results show that the antecedent rainfall can play significant role in decreasing the slope stability. This could reduce the stability of slope as severe as the rainstorm, despite that the flux intensity of antecedent rainfall is much lower than that of the rainstorm. Meanwhile, the influence of slope hydraulic conductivity is also crucial to result in the delay of landslide occurrence.

Therefore, low intensity of long sustained rainfall can result in slope stability reduction and landslides provided that the hydraulic conductivity of the slope is low (about 2.51×10^{-6} m/sec) and initial position of groundwater table is shallow (about 1 m to 3 m depth).

REFERENCES

Brand, E.W. 1984. Landslides in Residual Soils. *Proc. of the Speciality Session on Landslides, Symposium on Gotechnical Aspects on Mass and Material Transportation*, Bangkok, pp.87-117.

Gostelow, T.P. 1991. Rainfall and Landslides. *Prevention and control of landslides and other mass movement*, eds. Almeida-Taxeira M.E. et al, pp. 39-61. Commission of the European Communities, Report EUR 12918 EN.

Heath, W. 1984. Landslide Problems in Indonesia, particular those related to road development. Unpublished.

Heath, W., Saroso, B.S., Dowling, J.W.F. 1988. Highway slope problems in Indonesia. Paper presented on *the 2nd International Conference on Geomechanics in Tropical Soils*, Singapore *(unpublished)*.

Heath, W., Saroso, B.S. 1988. Natural slope problems related to roads in Java, Indonesia. *Proc. of the 2nd International Conference on Geomechanics in Tropical Soils*, Singapore, pp.259-266.

Karnawati, D. 1996. Mechanism of rain-induced landsliding in allophanic and halloysitic soils in Java. Ph.D. Thesis. University of Leeds (unpublished).

Keene, A.G. 1992. Landslide failure at 20510 Callon Drive, Topanga, California, March 1978. *Geological Society of America Reviews in Engineering Geology, Volume IX*, Ed by J.E. Slosson, A.G. Keene and J.A. Johnson. pp.55-62.

Sugalang, 1989. Landslide in Ciloto area, West Java, Indonesia. *Master Thesis*, Tekniska Hogskolan I Lulea, Ulea University of Technology. Unpublished.

Whipkey, R.Z. and Kirkby, M.J. 1978. Flow within the soil. *Hillslope Hydrology, ed. M. J. Kirkby*, pp.121-145. John Wiley and Sons Ltd., New York.